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G 112-29 (=NLTT 18149), a Very Wide Companion to GJ 282 AB with a Common Proper Motion, Common Parallax, Common Radial Velocity and Common Age

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ABSTRACT

We have made a search for common proper motion (CPM) companions to the wide binaries in the solar vicinity. We found that the binary GJ 282AB has a very distant CPM companion (NLTT 18149) at a separation $s = 1.09°$. Improved spectral types and radial velocities are obtained, and ages determined for the three components. The Hipparcos trigonometric parallaxes and the new radial velocities and ages turn out to be very similar for the three stars, and provide strong evidence that they form a physical system. At a projected separation of 55733AU from GJ 282AB, NLTT 18149 ranks among the widest physical companions known.

Subject headings: Binaries: visual — Stars: individual (G112-29, GJ 282AB)

1. INTRODUCTION

Our long-standing interest in the properties of very wide binaries and their process of dissociation led us to search for additional common proper motions (CPM) companions to the primaries of our catalogue of wide binaries in the solar neighborhood (Poveda et al. 1994). Other authors have searched for CPM companions to nearby stars (e.g. Lepine & Shara 2002, Lepine & Bongiorno 2007, Chaname & Gould 2004, Makarov et al. 2008, Scholz et al. 2008) but these searches have usually set rather stringent criteria for the acceptable separations and proper motion differences, in order to eliminate, as far as possible, optical companions. For our purpose we set upper limits to the separations of 1.5°, to the difference

of the proper motions of $|\Delta\mu| \leq 0.05''$ yr^{-1}, and to the difference of the position angles of less than 10°. These limits would appear at first sight to be too generous, but we will discuss below some additional criteria to establish the physical nature of the system GJ 282AB - NLTT 18149 in particular. Here we note only that the extensively studied system composed of Proxima Centauri and α Centauri AB is believed to be a physical system (see e.g. Wertheimer & Laughlin 2006), despite the fact that Proxima has a separation of 2.18° from α Centauri AB, and a difference in the proper motion of $|\Delta\mu| = 0.11''$ yr^{-1}.

Our search produced a handful of interesting systems. In this paper, we concentrate on GJ 282AB - NLTT 18149, probably the most remarkable one. For the sake of conciseness we shall refer to this system as GJ 282 ABC. The distant companion, NLTT 18149, has a separation from GJ 282A of $s = 1.09°$ and a difference of proper motion $|\Delta\mu| = 0.029''$ yr^{-1}. We will show that all three components of this system have very similar Hipparcos parallaxes, radial velocities and ages, which, together, constitute strong evidence in favor of GJ 282ABC being a physical system.

2. SEARCH FOR A COMMON PROPER MOTION COMPANION TO GJ 282AB

Around every primary in our catalogue (Poveda et al. 1994) having $M_V \leq 9$ and a parallax in Hipparcos (155 primaries), we searched for common proper motion companions in the revised NLTT (Salim & Gould 2003), looking only at stars within a sphere of 22 pc centered on the Sun, in order to be consistent with the distance limit of our 1994 catalogue. The magnitude limit ($M_V \leq 9$) was taken because we showed that our 1994 catalogue is complete up to a distance of 22 pc for primaries brighter than this magnitude. We searched for CPM companions within a circle of 1.5° radius centered on each primary of our catalogue, differing in proper motion by less than $0.05''$ yr^{-1} and in position angle by less than 10° ($|\Delta\mu| \leq 0.05''$ yr^{-1}, $\Delta\theta \leq 10°$.). Note that the errors in the proper motions of the revised NLTT stars are of the order of 8 to 10 mas yr^{-1}. This would suggest that in order to find physical pairs one ought to take proper motion differences of this order. However, such stringent limits would cause us to miss interesting systems, in which for instance one component (or indeed both) is an unrecognized astrometric binary, which would introduce a "spurious" proper motion difference (due to orbital motion). Also, taking a proper motion difference of a few mas yr^{-1} will cause us to miss some of the most interesting, widest, bound systems (e.g. Proxima Centauri, which has a proper motion difference of 110 mas yr^{-1} from Alpha Centauri AB), or systems caught just in the process of dynamical disintegration (Rodríguez et al. 2005; Gómez et al. 2005, 2008; Allen et al. 1974; Allen et al. 2006; Sánchez

et al. 2008). Therefore, taking $|\Delta\mu| \leq 50$ mas yr^{-1} seems to be an adequate compromise to discover good candidates to wide CPM systems, whose physical association would need to be confirmed by additional criteria.

Our search revealed several distant companions to binaries. One of the most interesting cases is the system GJ 282 AB - NLTT 18149 (GJ 282ABC), having $|\Delta\mu| = 0.029'' \text{ yr}^{-1}$, $\Delta\theta = 6.4°$, $s = 1.09°$ (see Figure 1).

3. A COMMON PARALLAX: ESTIMATE OF THE PROBABILITY OF C BEING AN OPTICAL COMPANION

Since we take rather generous upper limits for the separations and proper motion differences it is important to show that the putative CPM companions we find are not optical. In the case of GJ 282AB and NLTT 1814 we proceeded as follows.

The data for the parallaxes of GJ 282AB and NLTT 18149 given in the Hipparcos Catalogue are the following:

$$\begin{aligned} \pi(\text{GJ 282A}) &= 0.07044'' \pm 0.00094'' \\ \pi(\text{NLTT 18149}) &= 0.06985'' \pm 0.00153''. \end{aligned}$$

These parallaxes are so similar that they allow us to reject the possibility of NLTT 18149 being an optical companion to GJ 282AB. Indeed, from the differences of the Hipparcos parallaxes (and their quoted errors) we estimate that the "depth" of the system GJ 282AB-NLTT 18149) is at most 25 000 AU. This is less than the projected separation of GJ 282 AB-C, which is 55 285 AU, or about 0.25 pc, so we take the latter as the radius of a sphere and calculate the expected number of stars contained in this volume, using the number density determined from the luminosity function by Reid, Gizis and Hawley (2002), namely, $n = 0.112$ stars per cubic parsec. The expected number of stars (which could be optical companions) within this sphere is 0.0072. Next, from the frequency distribution of $|\Delta\mu|$ for a representative sample of the NLTT stars chosen at random we found the probability P($|\Delta\mu| \leq 0.05$) = 0.05. The probability of the proper motion vectors of GJ 282A ($\theta_A =$ 165.44″) and NLTT 18149 differing by less than 10° in position angle is less than 0.06, assuming the distribution of position angles to be uniform. To check this assumption we computed the position angles of the proper motion vectors of all the rNLTT stars situated in an area of 400 square degrees around GJ 282A (141 stars). Of these, 30 have position angles between 155.44° and 175.44°. Therefore, our estimate of the probability of the proper

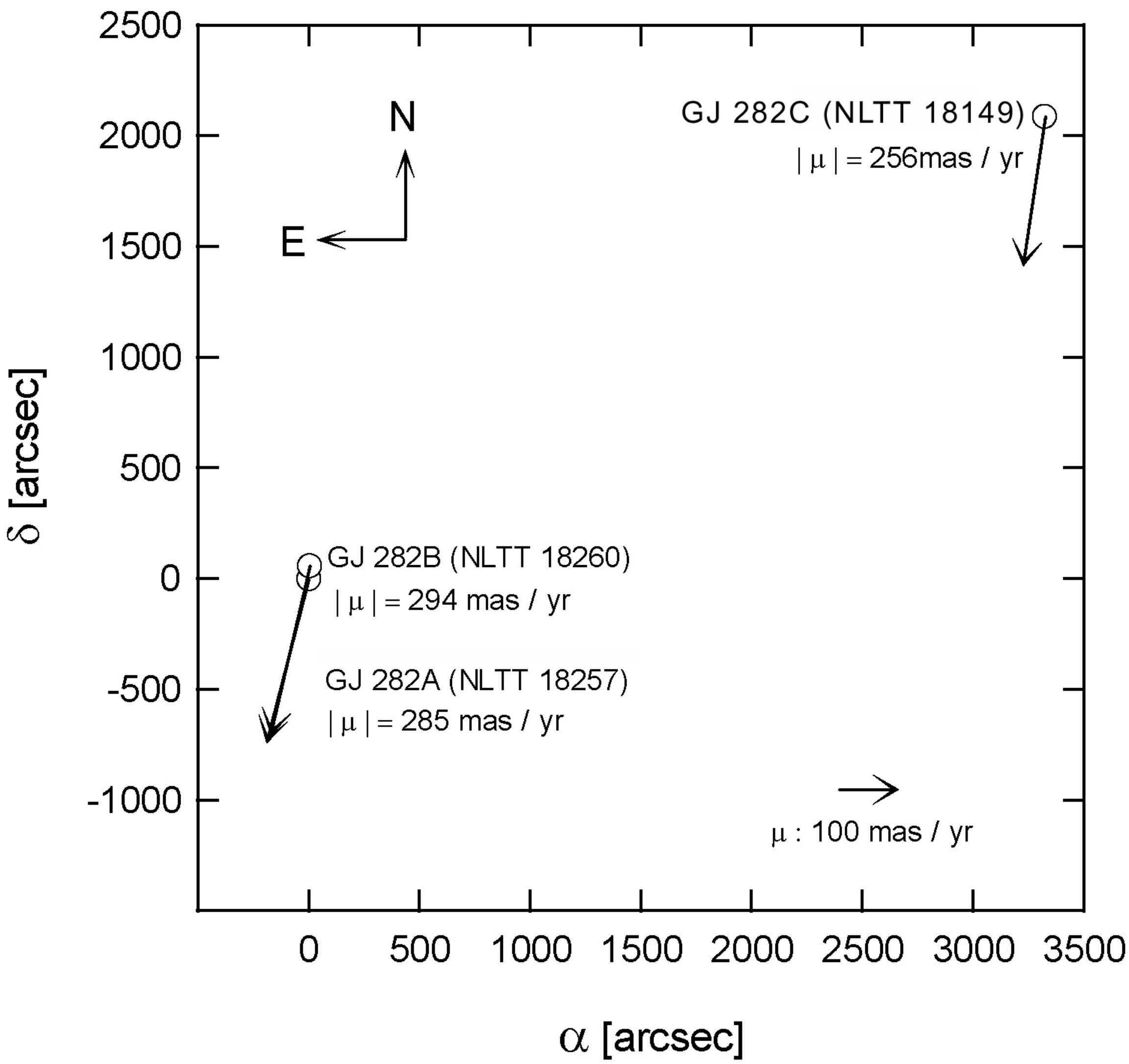

Fig. 1.— GJ 282 ABC. Relative positions and proper motions.

motion vectors differing by less than 10° has to be increased to $30/141 = 0.21$. Then, the the probability for one primary from our catalogue to have an optical NLTT companion satisfying these restrictions can be calculated to be $p = 0.05 \times 0.21 \times 0.0072 = 7.6 \times 10^{-5}$, and thus the expected number of opticals (satisfying the above conditions) associated to the 155 systems with $M_V < 9$ in our catalogue is about 0.01. In this manner, the similarity of the parallaxes and proper motions of the three components allows us to practically exclude

the possibility of NLTT 18149 being an optical companion to GJ 282AB

4. A COMMON RADIAL VELOCITY

4.1. Observations and spectral classification

The system GJ 282ABC was observed in 2008 January 19 with the Echelle spectrograph at the f/7.5 Cassegrain focus of the 2.1 m telescope of the Observatorio Astrónomico Nacional at San Pedro Mártir, B.C., México. The Site3 1024×1024 CCD was used to cover a spectral range from $\lambda 4000$ to $\lambda 7100$ Å with a spectral resolution of $R \approx 16,000$. Component A was observed twice, with exposure times of 130 and 300 s each; for component B we obtained a single 600 s exposure, and for component C three consecutive exposures, 900 s each. The data reduction was carried out with the IRAF package[1].

To classify both components of GJ 282 as well as NLTT 18149 = G112-29, we compared their spectra with those of the MK standard stars listed in Table 2. The latter spectra were obtained in a previous observing run (Dec. 2006) with the same equipment, but with a slightly smaller cross-dispersor angle, yielding a spectral covarage from 3800 to 6850 Å. With the exception of 61 Cyg A, which is contained in the list compiled by Morgan & Keenan (1973), these are the K0 to M3 main-sequence standards chosen by Torres-Dodgen & Weaver (1993), and all of them are included in the list of standards by Keenan & McNeil (1976). The comparison was made in the spectral range spanning from 4800 to 6800 Å. In classifying the stars we have excluded the Hα and Hβ lines, in order to avoid the possible effects of chromospheric activity, as implied by the BY Dra–type variability assigned to GJ 282A (=V869 Mon).

The spectrum of GJ 282A is intermediate to those of the K0 and K3- standards, but closer to the latter. In this spectral range the intensity of several lines increases rapidly with decreasing temperature. In Figure 2 we show an illustrative portion of the spectra of components A and B, together with those of the corresponding classification standards. Specially useful in this (and later) spectral ranges is the Sc I λ6210.7 Å multiplet 2 line, which is not contaminated with strong lines: it is very weak at K0 V then its intensity sharply increases up to the K7 V range and continues to increase, but more slowly, beyond. We conclude GJ 282A is a normal K2 V star, in accordance with previous classifications listed in Simbad. However, in the Simbad header for this object a K2Ve classification is given and

[1]IRAF is distributed by the National Optical Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

attributed to Cenarro et al. (2007). We certainly find no evidence of line emission in the entire observed spectral range for this star, and the intensities of the hydrogen absorption lines look normal for its spectral type. Cenarro et al. (2007) obtained Teff = 4833 K, log $g = 4.70$ and [Fe/H] $= -0.15$ for GJ 282A.

Reid et al. (2004) classified GJ 282B as a K5 V type star. Several line ratios in our averaged spectrum of this object are very similar to those of the K7 V MK standard. The strength of the above mentioned Sc I line implies a slightly hotter star, but other line ratios favor a somewhat later type (see Figure 2). With an uncertainty of 1 spectral subdivision, we estimate that GJ 282B is a K6.5 V normal star. The Hα line is moderately weaker in GJ 282B than in 61 Cyg B, while the relative intensities of Hβ to neighboring metalic lines are very similar in both stars, so there was little, if any, chromospheric activity in the object during its observation.

The averaged spectrum of NLTT 18149 = G 112-29 is intermediate between those of GJ 172 (M0.5 V) and GJ 15A (M2 V). The TiO and MgH molecular bands clearly point towards a slightly hotter star than the M2 V standard, in accordance with several line ratios sensitive to temperature in that spectral type range. In addition, Hα presents a weak, double-peaked emission; the peaks are separated by about 1.4 Å and the wavelength of the central trough –that nearly reaches the neighboring continuum level– is consistent with that at the rest frame of the star. Hβ is also weakly (but clearly) in emission, its width being larger than the instrumental profile, probably due to unresolved structure. Hγ and Hδ (with very poor S/N ratio) both appear as very narow emission lines. Hence, we classify this star as an M1.5 Ve star with a small uncertainty (0.5 of a spectral subdivision). Our classification results are given in Table 1.

4.2. Radial velocities

Accurate radial velocities for five of the standards listed in Table 2 have been obtained by Nordstroem et al. (2004) in the CORAvEL system. In order to check for self consistency or possible small variations in the velocities published for these five stars, we first cross-correlated the spectrum of each one with that of the other four, in the $\lambda\lambda$ 5132-5802 Å spectral range, adopting the velocities published by those authors, and using the IRAF *fxcor* task. The resulting average velocities were in good agreement with the published ones, except for that obtained for GJ 105A, which was found to be 23.5 ± 0.14 km s^{-1} (standard deviation of the velocity as obtained from the four template stars) slightly but significantly smaller than the published value. When the exercise was repeated, now substituting the velocity of GJ 105A with the one we obtained, the average radial velocities of the other four

spectral standards differed by less than 0.3 km s^{-1} from the published values, with a $\sigma \leq 0.2$ km s^{-1}. These five stars constitute the reference system against which we cross-correlated the spectra of GJ 282 A, B and C, using the radial velocities listed in the last column of Table 2 and the spectral range mentioned above. The resulting velocities do not show any dependence on the spectral type of the template stars, though the formal errors yielded by the IRAF *fxcor* task (between 0.5 and 3.0 km s^{-1}) are smaller for the velocities obtained from comparison stars with temperatures close to that of the corresponding object.

The average heliocentric radial velocities so obtained are -21.8 km s^{-1} for GJ 282A, -22.0 km s^{-1} for GJ 282B, and -22.7 km s^{-1} for NLTT 18149, respectively. The standard deviation from the mean for the velocities derived from each template star is less than 0.2 km s^{-1} for all three velocities, whereas their external error is estimated to be 1.5 km s^{-1}. Of course, the zero point of these measurements is linked to the CORAVEL system. To our knowledge, of these three stars only GJ 282A has previously published radial velocities, most recently by Nordstroem et al. (2004). These authors find a value of -18.6 ± 0.1 km s^{-1} for the radial velocity of this star, as derived from 11 spectra obtained during 13 years, and assign a probability of 0.62 for the observed velocity scatter to be due only to random observational errors. Since this velocity was measured on the same radial velocity frame as those we obtained, the difference between their value and ours (3.2 km s^{-1}) is significant and could be due to a small systematic error in the wavelength calibration of our spectra. However, if real, such an error would be irrelevant for the purpose of this paper.

In order to improve our estimate of the precision of the velocities we cross-correlated the two spectral standards with no published CORAVEL-based radial velocities, with the same five standards as above. The resulting velocities were $+33.2 \pm 0.6$ km s^{-1} for GJ 172 and $+31.5 \pm 1.6$ km s^{-1} for GJ 752A, which are, respectively, 2.0 and 0.9 km s^{-1} smaller than the velocities given by Evans (1967) and listed in Table 2. Hence, we estimate the precision of the radial velocities here obtained to be, at most, 2 km s^{-1}.

To directly measure the radial velocity differences between the three components of GJ 282, we additionally cross-correlated the spectra of A and C with that of component B; we obtained $A - B = +0.1 \pm 1.0$ and $C - B = -0.7 \pm 0.6$ km s^{-1}, in excellent agreement with the differences obtained from the velocities measured through the template stars.

We conclude that, when measured on the same reference system, the three objects have, within errors, the same heliocentric radial velocity. The slightly different velocity of component C will be further discussed in Section 6.

5. A COMMON AGE

Since at least one of the components of this system is a late-type Hα-emission, chromospherically active star, we suspected them to be X-ray sources. In fact, the three components of this system turn out to be bright X–ray sources, as observed by the ROSAT satellite. A relation between the X–ray luminosity L_x and the age T of low mass stars was obtained by Kunte, Raio and Vahia (1988). A similar relation has been recently discussed by Mamajek and Hillenbrand (2008), who find that coronal activity as measured by the fractional X–ray luminosity $L_x/L_{\rm bol}$ has almost the same age-inferring capability as does chromospheric activity measured through the Ca II H and K emission index. We will use both the Kunte et al. and the Mamajek & Hillenbrand relations to estimate the ages of the three stars.

To calculate the ages, X–ray luminosities were taken from the NEXXUS 2 Database, and bolometric luminosities were calculated from the observed $V - K$ color index, as given in the Simbad database. These quantities and the calculated ages according to the two relations used are listed in Table 3:

¿From the straight line fit given in Figure 1 of Kunte, Rao, & Vahia (1988) we obtain the relation

$$\log T = 5.63 - 0.654 \log(L_x/L_{\rm bol}),$$

from which we calculate the ages given in Column 4 of Table 3.

On the other hand, from equation (A3) in Mamajek & Hillenbrand (2008), namely

$$\log T = 1.20 - 2.307 \log(L_x/L_{\rm bol}) - 0.1512[\log(L_x/L_{\rm bol})]^2,$$

we find the ages given in the last column of Table 3.

Table 3 shows that the ages of the three components turn out to be very similar. If we assume that GJ 282A and B are coeval, then their age difference is a measure of the uncertainties in the age determination. Then, the ages of all three stars are equal to within these uncertainties.

6. DISCUSSION AND CONCLUSIONS

The four properties shared by the system GJ 282 AB-NLTT 18149, to wit, common proper motions, common parallaxes, common radial velocities and common ages, constitute

strong arguments in favor of a physical association of the three stars. Nonetheless, the difference in their proper motions $|\Delta\mu| = 0.029''$/year is large enough (compared to the error) to be a cause for concern.

There are several possible explanations for this difference. Physically bound systems with large angular separations may have slightly different μ_α, μ_δ, v_r simply due to projection effects. Orbital motion of GJ 282AB may also cause such differences. We examine each of these effects in turn. To assess the importance of projection effects we assume that the space motion of G112-29 is identical to that of GJ282A. Using the standard formulas (e.g. Smart 1962, p.16) we calculate the $\Delta\mu_\alpha$, $\Delta\mu_\delta$, and Δv_r resulting from the different positions and distances of GJ 282A and G112-29. We obtain $\Delta\mu_\alpha = 0.007''$ yr^{-1}, $\Delta\mu_\delta = 0.004''$ yr^{-1} and $\Delta v_r = 0.23$ km s^{-1}. These values are much smaller than the observed differences, and hence we conclude that the latter are not due solely to projection effects.

To estimate the importance of orbital motion of the pair GJ 282AB we need the masses of both components. These were calculated from their photometry and the mass-luminosity relation of Reid et al. (2002), and turn ut to be $M_A = 0.7\ M_\odot$, $M_B = 0.5\ M_\odot$. Assuming the orbit to be circular and perpendicular to the plane of the sky, we obtain a maximum contribution to the radial velocity of $\Delta v_r = 0.49$ km s^{-1}. The maximum contribution to the tangential velocity is also 0.49 km s^{-1}, which corresponds to a maximum proper motion of $|\Delta\mu| = 0.007''$ yr^{-1}, much smaller than the observed $|\Delta\mu| = 0.029''$ yr^{-1}. Conversely, if the orbit is in the plane of the sky, we obtain a maximum contribution to the proper motion of $|\Delta\mu| = 0.007''$ yr^{-1}, again much smaller than the observed $\Delta\mu$. In this case, orbital motion contributes nothing to the observed Δv_r. We conclude that the orbital motion of GJ 282AB could marginally account for the observed Δv_r, but even in the extreme case of an orbit wholly in the plane of the sky cannot account for the observed $|\Delta\mu|$. If the orbit is eccentric, we have to multiply these values by at most a factor of 1.4, but the conclusion remains unchanged.

Having shown that both projection effects and orbital motion cannot explain the discrepancy of $|\Delta\mu| = 0.029''$ yr^{-1} we suggest that the system GJ 282 AB - NLTT 18149 is in the process of dynamical disintegration. It would not be a unique case. There are at least two other multiple systems that appear to be in a similar state. The system θ_1 Orionis ABCD - E (Allen, Poveda & Worley 1974; Allen, Poveda & Hernández-Alcántara 2006; Sánchez et al. 2008) has been shown to be in the process of ejecting component E, and the system composed of BN - I - n (Rodríguez et al. 2005, Gómez et al. 2006) is also disintegrating. Thus, GJ 282AB-NLTT 18149 could be another member of the interesting new class of systems caught in the process of gravitational disintegration. A rough calculation shows that component C would have been ejected about 60,000 years ago. This value is much smaller than the

estimated ages of the stars, which implies that the dynamical evolution of the hypothetical bound triple ABC proceeded slowly during most of its lifetime, before C finally escaped.

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Table 1: Some Astrometric and Physical parameters of GJ 282AB and NLTT 18149

GJ	NLTT	$\pi^{(1)}$ [mas]	$\mu_\alpha^{(2)}$ arcsec yr^{-1}	$\mu_\delta^{(2)}$ arcsec yr^{-1}	μ arcsec yr^{-1}	$V_r^{(3)}$ km s^{-1}	sep $''$	sep AU	Sp$^{(3)}$
282A	18257	70.44	0.0717$^{(4)}$	-0.2761$^{(4)}$	0.2852	-21.8			K2V
282B	18260		0.0668	-0.2862	0.2939	-22.0	58	824	K6.5V
282C	18149	69.85	0.0363$^{(4)}$	-0.2535$^{(4)}$	0.2561	-22.7	3892	55733	M1.5Ve

(1) Simbad - CDS. (2) Salim and Gould (2003). (3) This paper. (4) The proper motions given in van Leeuwen (2007) for components A and C are, in arcsec yr^{-1}, $\mu_\alpha(A) = 0.0699$, $\mu_\delta(B) = -0.2786$, $\mu_\alpha(C) = 0.0374$, $\mu_\delta(C) = -0.2534$. No proper motion for component B is listed.

Table 2: Standard stars used in this paper

Name	HD	Sp.T.	Pub. V_r km s^{-1}	Adopted V_r km s^{-1}
σ Dra	185144	K0 V	+26.3$^{(1)}$	+26.3
GJ 105A	16160	K3- V	+25.1$^{(1)}$	+23.5$^{(3)}$
61 CygA	201091	K5 V	−66.5$^{(1)}$	−66.5
61 CygB	201092	K7 V	−65.3$^{(1)}$	−65.3
GJ 172	232979	M0.5 V	+35.2$^{(2)}$	
GJ 15A	1326 A	M2 V	+11.3$^{(1)}$	+11.3
GJ 752A	180617	M3 V	+32.4$^{(2)}$	

$^{(1)}$ Evans (1967) $^{(2)}$ Nordstroem et al. (2004) $^{(3)}$ This paper, see text

Table 3: Bolometric and X–ray luminosities, and ages

Component	L_x ergs	$L_x/L_{\rm bol}$	Age yr	Age yr
GJ282 A	2.45×10^{28}	3.45×10^{-5}	3.5×10^{8}	3.0×10^{8}
GJ282 B	5.75×10^{27}	1.27×10^{-5}	6.8×10^{8}	7.2×10^{8}
NLTT18149	1.48×10^{28}	3.86×10^{-5}	3.3×10^{8}	2.6×10^{8}

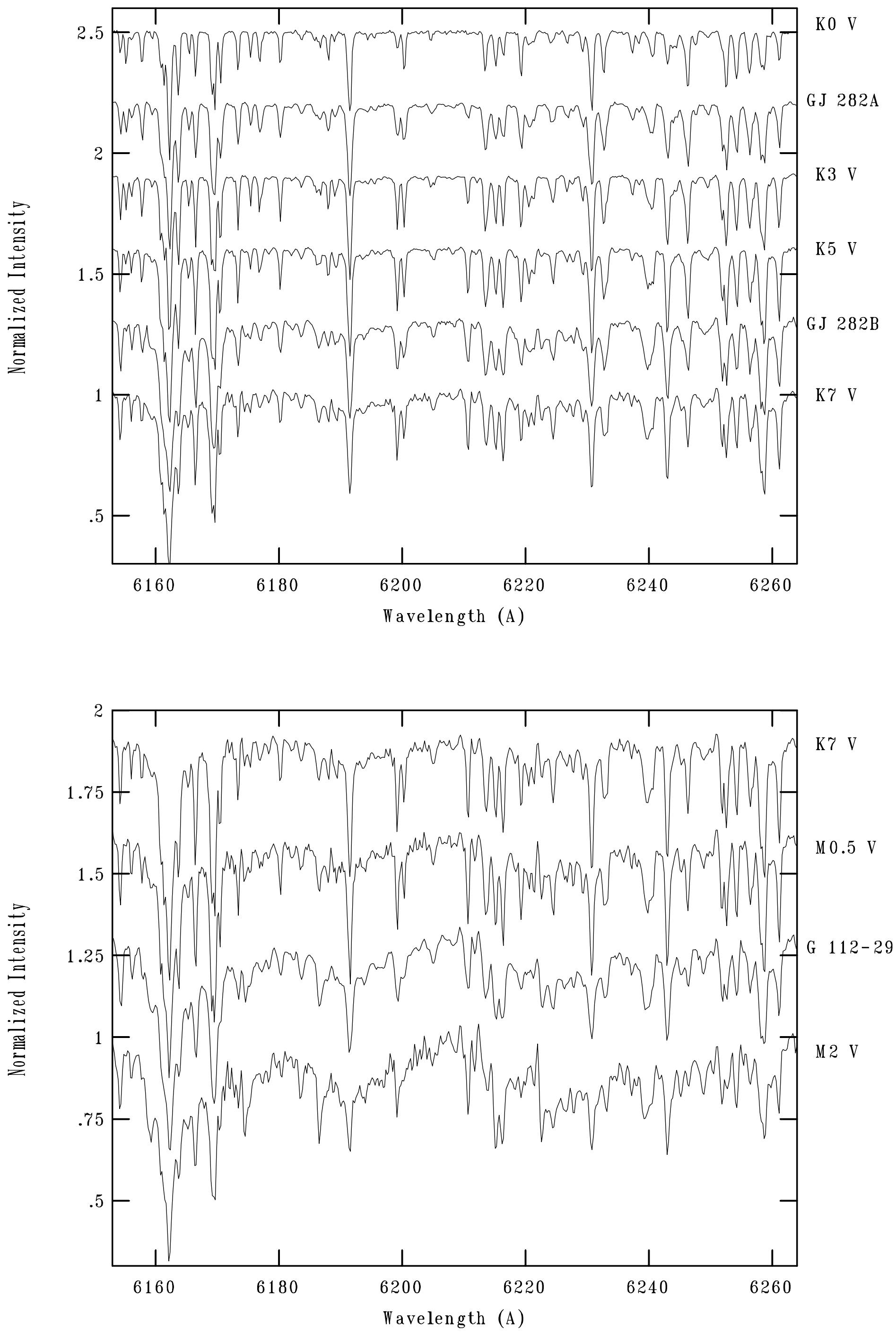

Fig. 2.— Top: Portion of the normalized spectra of GJ 282A and B compared with the MK spectral standards used to classify the objects (see Table 2). Each spectrum has been shifted 0.3 units above the previous one on the normalized intensity scale and referred to the observer's rest frame. Several line ratios change rapidly with spectral type, notably those of Sc I λ6210.7 Å and V I λ6198.2 Å relative to their neighboring lines. Bottom: Same as in Top, but for G 112-29 = GJ 282C. The spectrum of this star is clearly intermediate between M0.5 and M2, probably closer to the latter type as inferred from the stronger molecular